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MANNED AND REMOTELY OPERATED SUBMERSIBLE SYSTEMS: A COMPARISON

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MANNED AND REMOTELY OPERATED SUBMERSIBLE SYSTEMS: A COMPARISON

by

Howard Talkington

OCEAN TECHNOLOGY DEPARTMENT

June 1976

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NAVAL UNDERSEA CENTER, SAN DIEGO, CA. 92132

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ADMINISTRATIVE INFORMATION

This paper was originally presented as the keynote speech for the beginning of the workshop on "Manned Undersea Activities" sponsored by the National Academy of Engineering's Marine Board and held at Arlie House, Virginia, 17 to 21 October 1972. The purpose of the address was to focus the attention of a group of scientists and engineers whose primary interest and experience had been with manned submersibles on the potential of remotely manned undersea systems. In February 1973 the speech was published as NUC TN 953, Why Man? The present report extends the older technical note to include newly developed capabilities in both manned and remotely operated systems.

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This paper presents examples of undersea tasks and describes some of the vehicles that presently are available to accomplish them. It examines the reasons for placing man in a submersible system, concluding that the most important of these is his active, interpretive ability to see, and discusses the relative costs of building and operating manned and remotely operated vehicles. Finally, it suggests that remotely operated systems are better suited for the performance of most undersea projects for at least six reasons: relative economy of

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development in time and equipment costs, unlimited operational endurance on site by virtue of the cable link to the surface, surface control and coordination of project efforts, ability to perform in hazardous areas without endangering personnel, ability to change or modify all system components to meet individual tasks range needs without affecting system safety or certification status, and ease of changing crews without disrupting the mission.

SUMMARY

PROBLEM

Compare the relative capabilities of manned and remotely operated submersible systems.

RESULTS

This paper presents examples of undersea tasks and describes some of the vehicles that presently are available to accomplish them. It examines the reasons for placing man in a submersible system, concluding that the most important of these is his active, interpretive ability to see, and discusses the relative costs of building and operating manned and remotely manned vehicles. Finally, it suggests that remotely operated systems are better suited for the performance of most undersea projects for at least six reasons: relative economy of development in time and equipment costs, unlimited operational endurance on site by virtue of the cable link to the surface, surface control and coordination of project efforts, ability to perform in hazardous areas without endangering personnel, ability to change or modify all system components to meet individual tasks range needs without affecting system safety or certification status, and ease of changing crews without disrupting the mission.

RECOMMENDATIONS

Remotely operated systems should be considered first and used whenever and wherever possible. Where man's presence at the work site is essential, he should be given panoramic visibility to enable him to use his sight freely. Manned submersibles with large viewports or transparent pressure hulls are preferable.

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INTRODUCTION

The age of exploration is not over. Even while outer space beckons, the majority of our own planet remains unexplored: hydrospace has yet to be fully developed. The Nation is now prosecuting a program which has a declared goal of developing, promoting, and supporting a national operational capability for man to work under the sea in order to achieve a better understanding, assessment, and use of the marine environment and its resources. Whenever undersea work and exploration are discussed manned systems engender the most attention and interest in the participants. Here it is that we must first ask, why man? Although manned systems are useful, exciting, and, many times, necessary, the majority of undersea tasks facing man can be accomplished more safely and economically, and as thoroughly, with remotely manned systems. Guidelines for making the decision to use a manned or unmanned system for the execution of a specific undersea task are proposed and explained.

UNDERSEA TASKS

In order to provide a context for the following paragraphs three examples of undersea tasks are presented. These fall into the general categories of exploration, search and recovery, and work, but the vehicles described in each case can be used for other tasks as well. The projects cited are intended only to suggest the kinds of tasks that must be performed beneath the sea and the types of vehicles that might be available to accomplish them. The first example involves the *Trieste*, which was utilized in the Navy's pioneering efforts in the field of deep ocean engineering. The *Trieste* (Figure 1) was the first successful manned, deep-diving, free-swimming submersible. It was an innovation because it enabled man to dive into the depths of the sea in the relative safety and comfort of a one-atmosphere pressure hull. Because the hull was heavy steel, it required a large gasoline-filled float to give the submersible an overall neutral buoyancy. For looking at the undersea world outside the *Trieste* there was one viewport 10 centimeters in diameter in the steel pressure hull. This is the vehicle that carried man into the deepest part of the world's oceans — to the bottom of the Marianas Trench.

A later development of the design is *Trieste II*, presently the Navy's deepest diving submersible. Improvements in the electronic, acoustic, photographic, and high-pressure systems have extended *Trieste II's* ability to operate in the deep ocean (Figure 2).

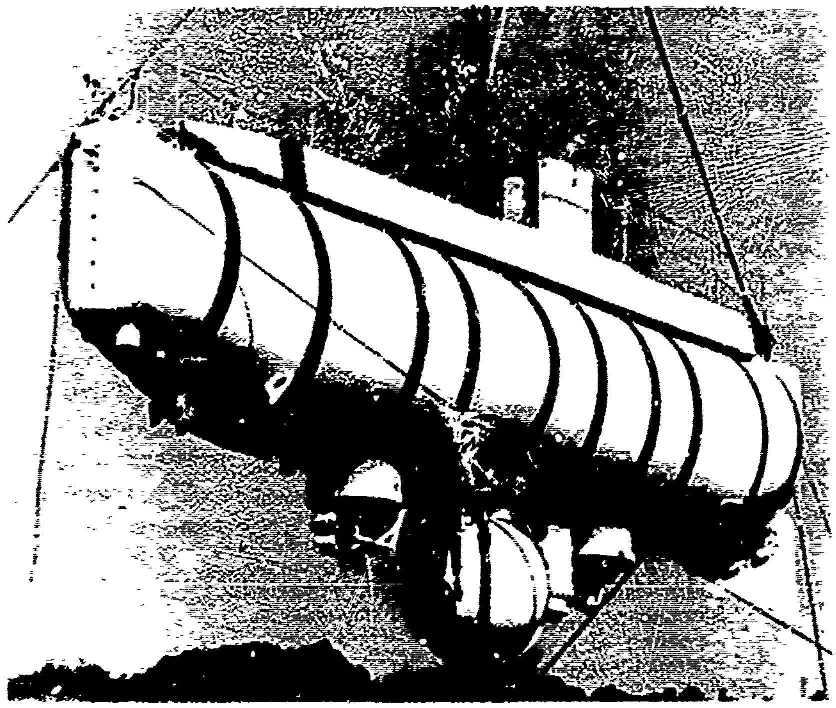

Figure 1. *Trieste* was the first successful manned, deep-diving, free-swimming submersible.

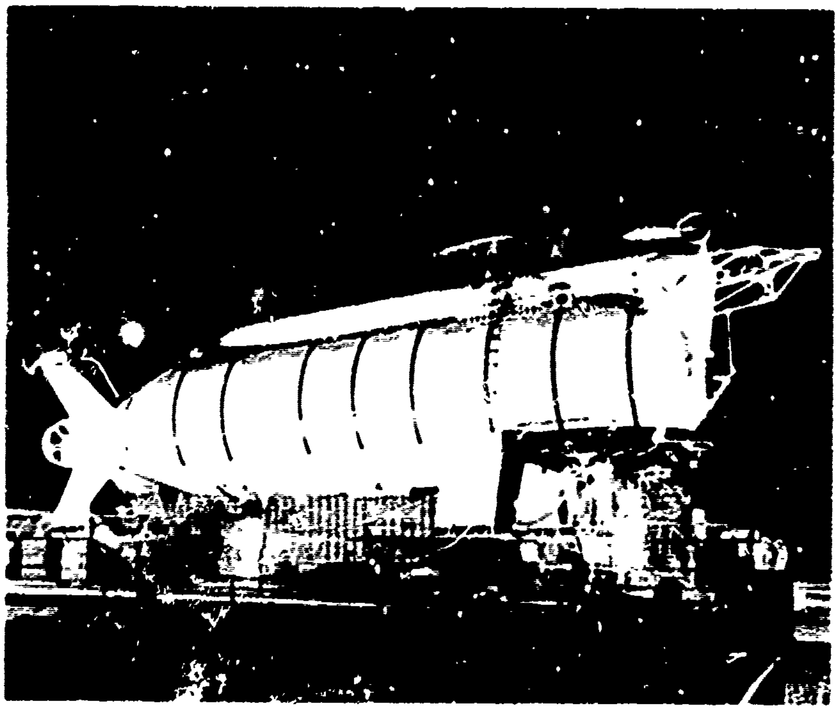

Figure 2. Design improvements have extended *Trieste II*'s ability to operate in the deep ocean

For the second example we must return to early 1966 and to the Mediterranean Sea where it touches Spain near the village of Palomares. Two aircraft of the U.S. Strategic Air Command had collided in midair and scattered wreckage and four H-bombs around Palomares. Three of the bombs were quickly found on land. But the fourth one was apparently lost in the sea; a fisherman had reported seeing a bomb-like object fall into the waves. For almost three months search and recovery efforts were diligently pursued. The efforts embraced every way man can extend himself under the sea: there were divers as well as manned and remotely manned systems. While divers worked the relatively shallow water, the manned Perry submarines, *Alvin* (Figure 3) and *Aluminaut*, searched the deeper, more rugged areas. The U.S.N.S. *Mizar* (Figure 4) provided an instrumented, unmanned sled (Figure 5) which enabled the searchers to examine a large (about 25 square miles, or 65 square kilometers) to depths, if necessary, of 20,000 feet (6,100 meters). The *Mizar* has a center well through which the sled is lowered and then towed at the selected depth.

The manned *Alvin* twice found the lost bomb; the remotely manned *CURV I* (for "Cable-Controlled Underwater Recovery Vehicle") was used to recover it. *CURV I* (Figure 3) had been developed for recovering test ordnance at the Naval Undersea Center's Long Beach and San Clemente Island test ranges to depths of 2,000 feet (610 meters). To meet the need at Palomares, *CURV I* was modified so it could work at greater depths.

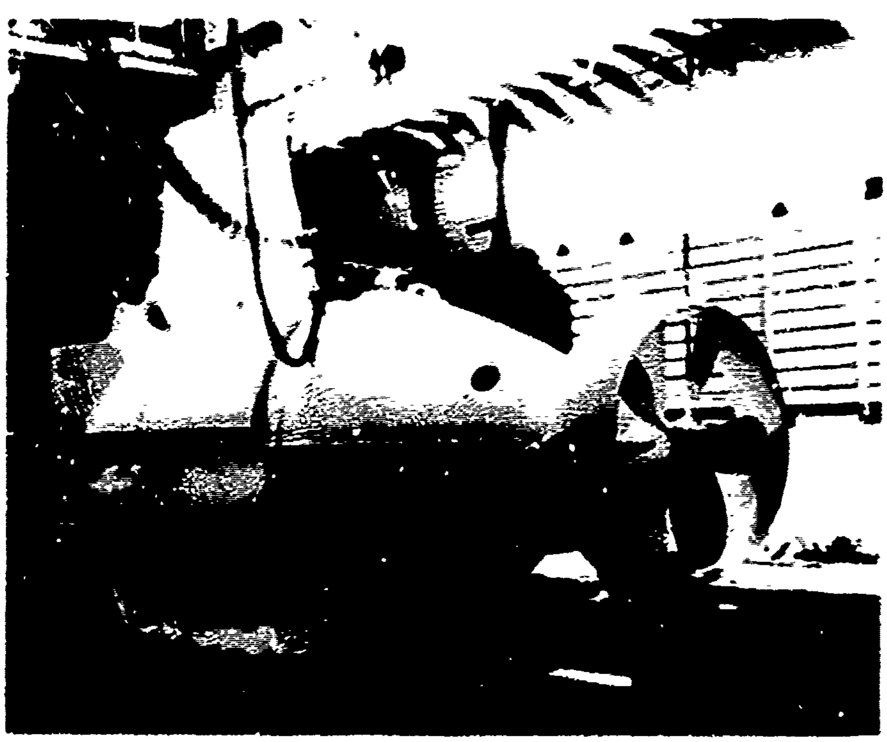

Figure 3. The manned submersible *Alvin* participated in the recovery of the H-bomb lost at sea off Palomares, Spain.

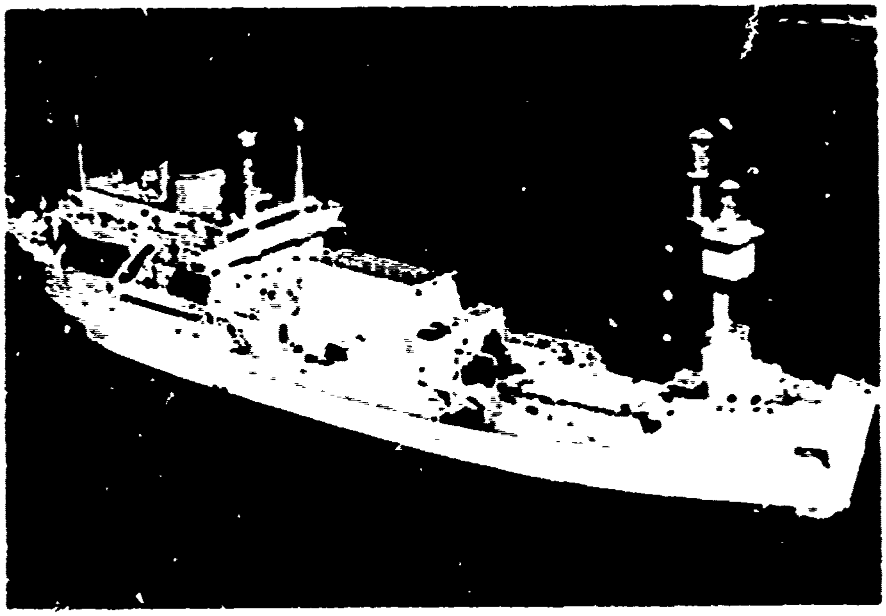

Figure 4. The support ship U.S.N.S. *Mizar* also took part in the search for the lost bomb.

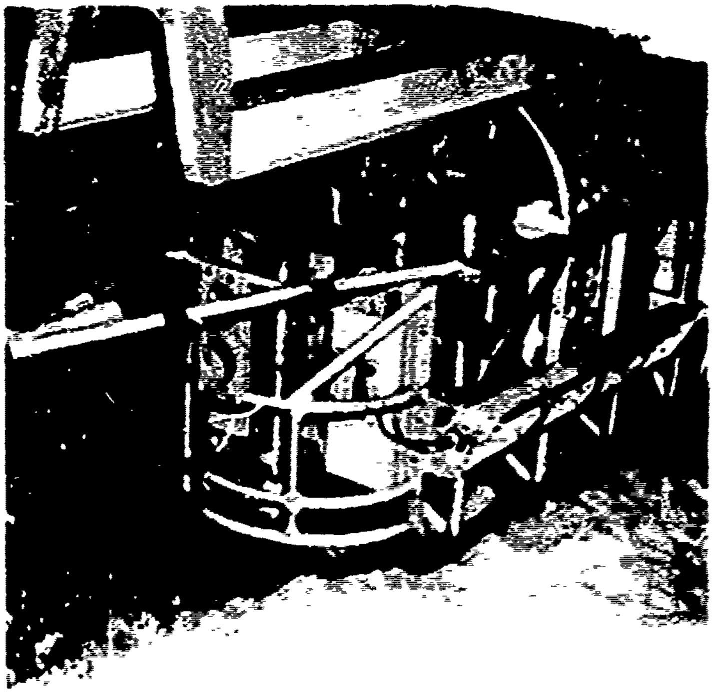

Figure 5 An instrumented, unmanned sled towed by the *Mizar* helped search a large area of the ocean floor

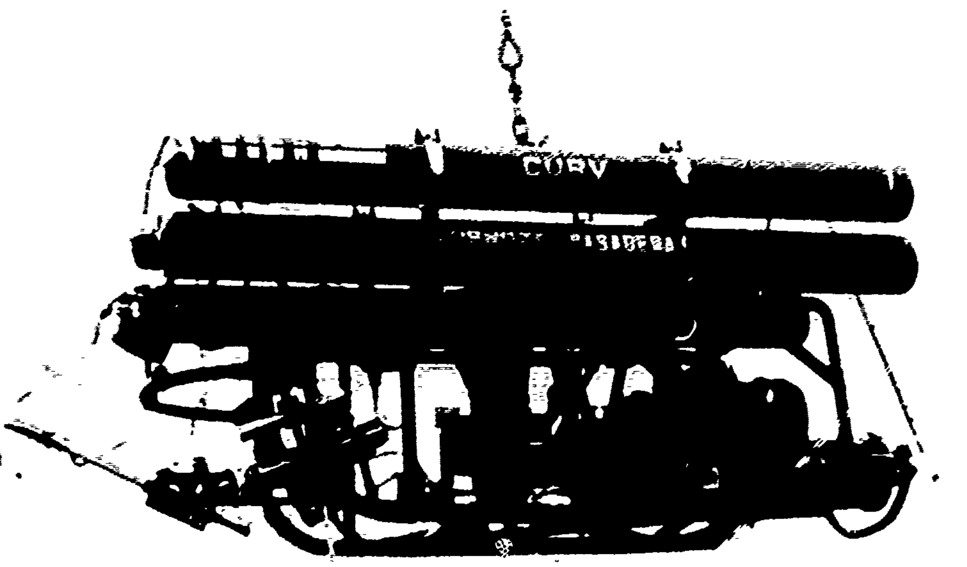

Figure 6. *CURV I* raised the lost H-bomb to the surface

The bomb was tenuously resting on a craggy slope at the brink of an undersea canyon, and the parachute that was still attached to it was drifting back and forth in the current. There were two dangers here for those attempting a recovery: the first was getting entangled in the parachute shrouds and the second was dislodging the bomb and possibly losing it deeper in the sea. When the bomb was first discovered, the *Alvin* attached a marking pinger, but it became entangled and there were some nervous moments before it worked itself loose. After that the *Alvin* preferred to stand back, and the remotely manned *CURV I* made the necessary attachments and raised the lost bomb to the surface (Figure 7) from a depth of 2,850 feet (869 meters). This was an intricate, tense, and vital example of different types of systems working together to conduct a successful operation.

The third example consists of a complicated task which was well handled by a remotely manned system, *CURV III*. A major overhaul was scheduled for the Azores Fixed Acoustic Range (AFAR), and *CURV III* was selected as the underwater work platform. *CURV III* (Figure 8), the most versatile in the *CURV* series of remotely manned vehicles, has all the necessary equipment for searching for, locating, recovering, and documenting the recovery of a lost item or the completion of a particular support task at depths to 7,000 feet (2,300 meters). This necessary equipment comprises both active and passive sonar, two closed-circuit TV systems, a 35-mm documentary camera and strobe, and an underwater lighting system. The standard work tool is an electrohydraulically operated manipulator, special

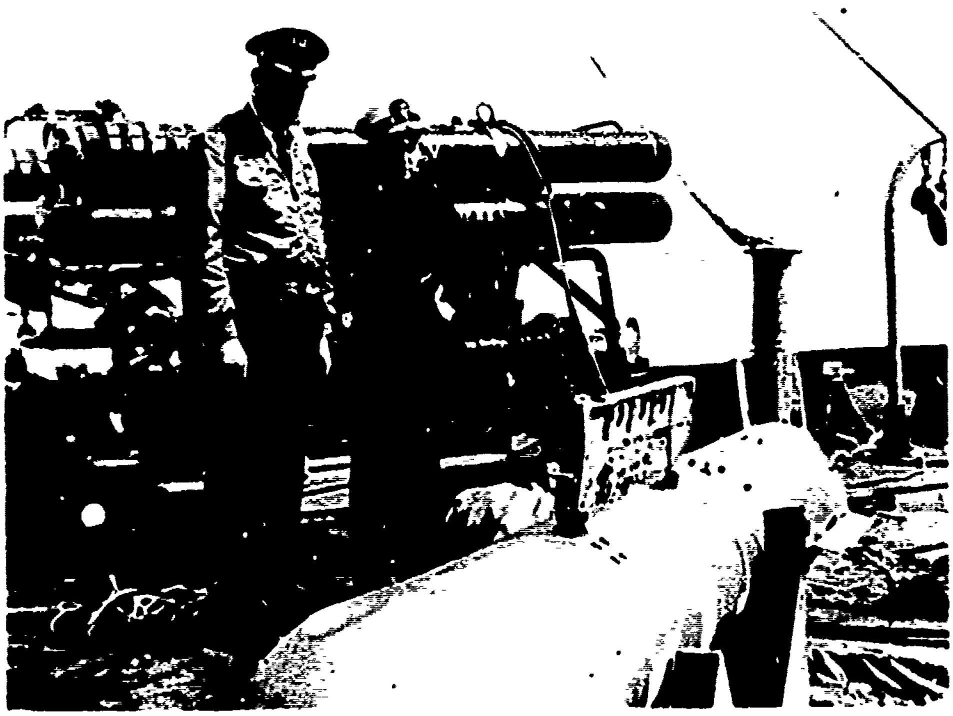

Figure 7. The bomb recovered off Palomares, Spain.

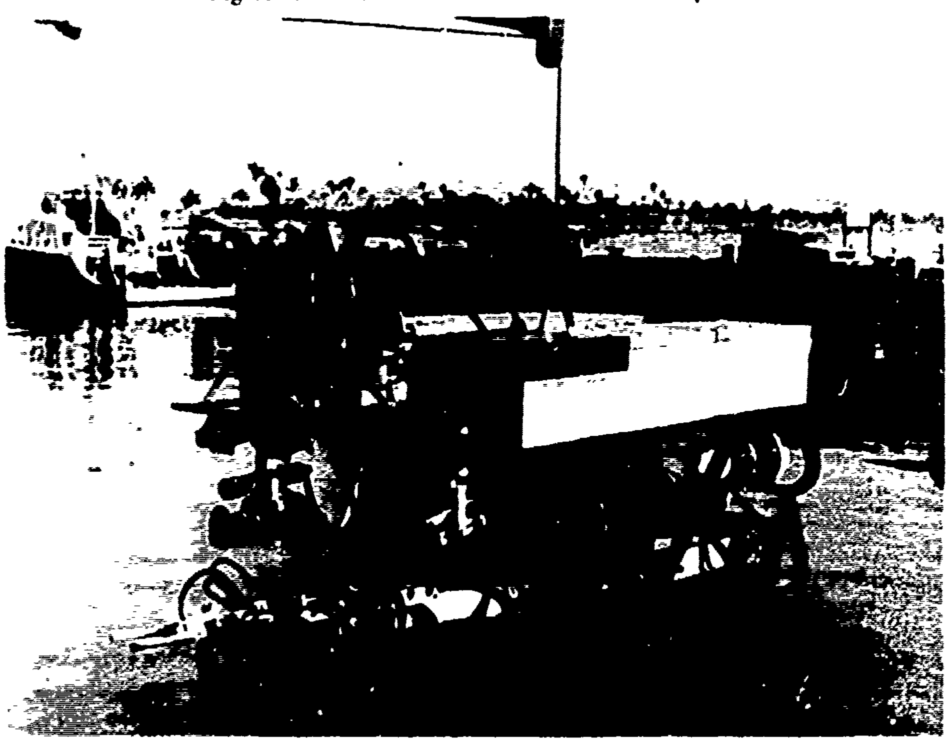

Figure 8 *CURV III* has proven to be a versatile, reliable system able to operate to depths of 7,000 feet (2,300 meters).

work tools and equipment, however, can be readily attached to the vehicle. Before *CURV III* performed the tasks it was assigned to do at AFAR, engineers reviewed the requirements and supervised the special modifications which equipped *CURV III* to accomplish its mission. The tasks accomplished by *CURV III* at AFAR included rigging one of the 125-foot (38- meter) acoustic towers so that it could be lifted from the sea floor, cutting various underwater electric cables that were from 1.5 to 3.5 inches (38 to 89 millimeters) in diameter, retrieving underwater electric cables from the ocean floor (Figure 9), sonar mapping of the acoustic tower sites, and inspecting the underwater range once all the other tasks had been successfully completed.

WHY MAN?

While keeping the above examples of undersea tasks in mind, let us return to the question – why man? Man's attempt to learn about the world he lives in has most often been conditioned by the clash between desire and economics. What he wants to do usually far exceeds what he can afford to do. Columbus spent years in search of funding before he was able to finally set sail for the New World. The Apollo Program has become history; the absence of funds truncated the list of desired goals. In considering our goal of fully using the marine environment and resources, we must investigate the effect of putting man into a submersible system. How does he impact the relationship between desire and economics? This question should be answered before any system is made the focus of time, effort, and money.

First, we must be honest with ourselves about ourselves. Man has the desire to see, to know, to be there. He has an ego: he wishes to leave his personal mark, he wants others to acknowledge that achievement, and then he pushes on. A flag could be planted on top of Mount Everest by dropping it from an aircraft, and that would indeed bring one level of satisfaction. However, to set the flag at the summit – after having scaled the heights of the icy mountain – that is the supreme satisfaction, the supreme accomplishment. This is the glory of a goal personally attained. That man is a searching, conquering, proud being must be taken into account; because this conviction affects the thinking of everyone who establishes goals for an undersea project, especially those who always insist that man must be present at the work site. It is not being said here that this conviction is good or bad, but only that it exists and must be recognized.

Beyond the desire for personal accomplishment there are other reasons man should or could be included in an undersea work or exploration system. The poet, Dylan Thomas, has a line which reads "when all my five and country senses see." Man is a sensing creature possessing an integrated, coordinated, active intellect. And when a man's trained intellect is part of a system, he is able to repair, reset, adjust, and adapt, in short, respond to the unusual situation. He can perform a variety of tasks because of his general orientation and versatility. The free-swimming diver comes closest to exercising directly his senses in the ocean (primarily seeing, touching, and hearing). The man in the manned submersible, however, is sensing his environment remotely, except for one sense – that of sight. In the unmanned system all

Figure 9. Underwater cables were retrieved by *CURV III* during its work at the Azores Fixed Acoustic Range (AFAR).

sense data is remotely perceived. Thus, this system is "remotely manned," for man's intellect and senses are still a part of the overall system, but they are applied remotely to the work site. Therefore, the primary reason for placing man at the scene is to make use of his active, interpretive ability to see.

THE COST OF MANNED SYSTEMS

This seeing man is the one that is placed in a manned system; but there should be irrefutable reasons for putting him here, because the cost is high for risking a human life in a hostile environment. There is the safety factor, which makes it necessary that the system sustain and support human life. Therefore, funds must be allocated to support man and not be directed toward accomplishing the basic goal. An adequate life support system substantially increases the weight and complexity of the whole system, and, therefore, the cost. Because manned systems are not currently powered from the surface, they require a self-contained power supply comprising special high-energy storage and charging systems. The power supply increases the weight and volume of the system, and it generates power for only a relatively short time, thus severely limiting mission endurance both of these facts represent a costly impact on system effectiveness. When man is in the system he must be protected from the hostile environment by a pressure hull. Since the pressure hull is usually made of steel, it becomes the largest, heaviest, and most costly part of a manned submersible. Once the manned submersible is constructed it must undergo man-rating certification. This

procedure of tests and documentation is not only costly in itself, but it imposes necessary and costly design constraints that all support components and subsystems must meet. Along with the safety factor is the anxiety factor: when the *Alvin* was entangled in the bomb's parachute shrouds there was a great deal of concern for the safety of those on board. However, if a remotely manned system had been entangled that parameter of anxiety would not have existed. A man in a system also complicates the already difficult problem of handling because manned systems, besides being larger and heavier, require a special fail-safe handling capability and any accidental rough handling could result in injury or death. This handling capability also adds expense to the system. So the following questions must be considered when designing a system for undersea tasks. Where do we need man in the system? Do we really require his presence at the work site? Could he be used more effectively at the surface (taking advantage of the longer mission duration potential for instance)?

Experience with the *Deepstar-4000* illustrates what has been said. Many dives made use of the man inside, made use of his ability to be an active observer. Yet that was not always the case. In order to meet some specific test objectives, *Deepstar* carried a full complement of scientific instrumentation (Figure 10), including sound velocimeters, salinometers, water sampling devices, and a coring device. It was noted that during many of the test dives the scientist inside the submersible was so busy that he never looked out the viewport. Of course, the question must be asked: Did the "observer" need to be there on a site? He used none of his senses to learn about the environment. Could these particular tasks have been accomplished just as well (and more safely and economically) with a remotely controlled system?

REMOTELY MANNED SYSTEMS AND USE OF THE OCEANS

Table 1 presents a list of ocean exploration and survey parameters compiled by the Panel on Platforms for Ocean Exploration and Surveying of the National Academy of Engineering's Marine Board. The list shows which parameters are pertinent at each of five separate levels: the air-sea interface (+10 m to - 10 m), the upper water column (-10 m to -500 m), the lower water column (-500 m to bottom), ocean floor, and subbottom. This is illustrative of what scientists feel is necessary to better understand, assess, and use the marine environment and its resources. Not only are there many parameters to be measured, but they must be measured in many areas of the world before the oceans which cover three quarters of the earth can be fully utilized. Many measurements in many areas is the desired goal, but once again economics affects accomplishment. It was the conclusion of the panel that buoy systems and unmanned systems should be used whenever possible because they would enable scientists to get the maximum amount of information for their dollars. This would avoid the expense of using a manned system such as *Deepstar* when the only responsibility of those on board is to ferry the instrumentation to the appropriate level for gathering data. When man is put into a system there must be a specific, necessary purpose for having him there, and he must achieve that purpose.

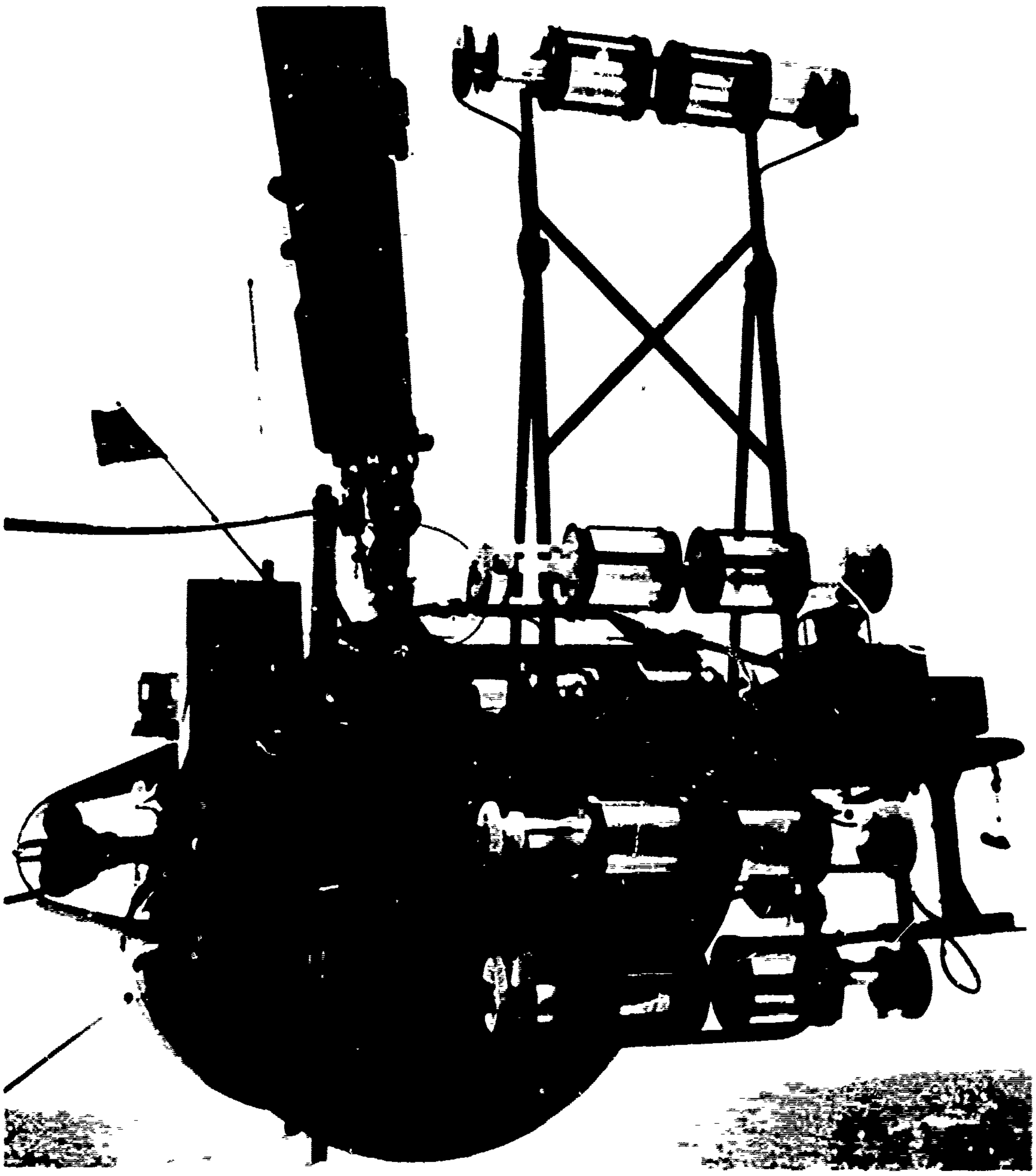

Figure 10. Manned submersible *Deepstar-4000* has carried a variety of instruments for taking oceanographic data; these data could be taken by remotely operated systems.

Table 1. Ocean Exploration and Survey Parameters.

Parameter	Air-Sea Interface (10 to -10 m)	Upper Water Column (-10 m to -500 m)	Lower Water Column (-500 m and deeper)	Bottom	Subbottom
1 Ice	X				
2 Sea-swell-surf	X				
3 Surface meteorology	X				
4 Surge	X				
5 Tides	X				
6 Currents	X	X	X		
7 Hydrodynamic forces	X	X	X		
8 Noise	X	X	X		
9 Salinity	X	X	X		
10 Temperature	X	X	X		
11 Turbidity	X	X	X		
12 Biomass	X	X	X	X	
13 Nutrients	X	X	X	X	
14 Oxygen	X	X	X	X	
15 Pollutants	X	X	X	X	
16 Electrical		X	X	X	
17 Bathymetry				X	
18 Geomorphology				X	
19 Rheology				X	
20 Engineering properties				X	X
21 Geochemistry				X	X
22 Geology				X	X
23 Geothermal				X	X
24 Physical properties				X	X
25 Radiometric				X	X
26 Gravity					X
27 Magnetics					X
28 Seismic					X

Buoy and unmanned systems are available now for the data gathering that will yield the information most useful to man. Two such systems are *Sonodiver* and *Sparbuoy*. Sonodiver is a buoyancy-actuated system designed to gather acoustic and other environmental data at predetermined depths to 6,100 meters. It is approximately 3 meters long and 0.46 meter ir diameter (Figure 11 a, b). In operation, *Sonodiver*, once launched, descends, releases it escent weight, hovers, takes data, releases its ascent weight, and returns to the surface (Fi e 12). Its data are recorded on magnetic tape that can be played back aboard the support ship after recovery. *Sparbuoy* is a surface unit that deploys a hydrophone to depths up to 100 meters. The hydrophone is decoupled from wave action by the catenary configuration of its cable. *Sparbuoy*, which is the same size as *Sonodiver* but carries a mast 6 meters long, transmits data continuously to shipboard recorders (Figure 13 a, b). When the two units are used together, *Sparbuoy's* data help to determine whether changes in ambient noise measured by *Sonodiver* are caused by changes in depth or are the result of a general variation in the ambient noise level.

Another example of the present capabilities of unmanned systems is *Seaprobe* (Figure 14). The *Seaprobe* ship has a drillstring with an instrument pod attached which has a large manipulating capability built into it. This system has shown that man can work at extreme ocean depths and that he can extend his senses – hearing and seeing – and his manipulative abilities from the safety of the surface to the location requiring his attention. The *Seaprobe* has operated effectively and proved to be a very good remotely operated system; it has successfully completed a task which required its capabilities for the handling of array systems in the Bahamas.

Other remotely manned systems come in a variety of shapes and sizes dictated by their intended applications. The larger systems include *CURV III*, already mentioned, and *RUWS* (for "Remote Unmanned Work System"), constructed under the Deep Ocean Technology Program for experimental tasks in the deep ocean. *CURV III* is 6 1/2 by 6 1/2 by 15 feet (2.1 by 2.1 by 4.9 meters). It weighs 4,500 pounds (2,040 kilograms) in air and can operate to depths of 7,000 feet (2,300 meters). The vehicle is designed so that all its major operational components can be disassembled and installed on any surface craft with adequate deck space. This capability has enabled the vehicle to perform successfully under emergency conditions. When the manned submersible *Pisces III* sank off Cork, Ireland, in 1973, *CURV III* was flown from North Island Naval Air Station to Cork with its support equipment and crew by two U.S. Air Force C-141 transports. Embarked on the Canadian Coast Guard Ship *John Cabot* the men and equipment reached the location of the sinking less than 48 hours after the Naval Undersea Center was asked to assist in the rescue effort. In very rough water estimated as sea state six *CURV III* found the downed submersible at a depth of 1,500 feet (458 meters) and attached a line by which it was raised. The two men aboard were recovered in good condition. This operation, performed from a ship of opportunity under harsh time constraints and in bad weather, demonstrated *CURV III's* versatility in gratifying fashion.

RUWS, unlike *CURV III*, is not tethered directly to its support ship. This experimental system includes a primary cable termination (PCT) frame that serves as a launch and recovery platform for the work vehicle (Figure 15). The PCT is 5 by 6 by 10.7 feet

Figure 11. (a) *Sonodiver* is a buoyancy-actuated system that measures ambient noise and other environmental parameters at depths to 20,000 feet (6,100 meters).

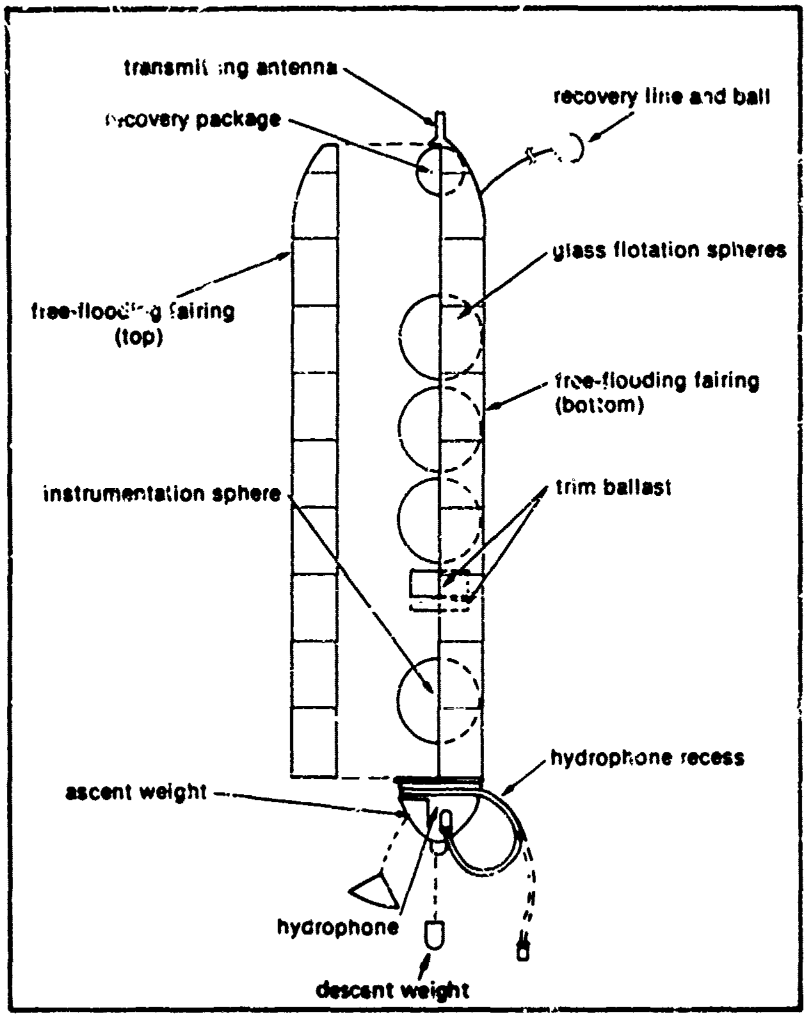

Figure 11. (b) *Sonodiver* is approximately 10 feet (3 meters) long and 1 1/2 feet (0.46 meter) in diameter. It releases weights to hover, then return to the surface.

(1.5 by 1.8 by 3.8 meters), while the work vehicle is 4 by 6 by 10.7 feet (1.2 by 1.8 by 3.8 meters). Total weight of the system is approximately 4,300 pounds (1,600 kilograms). The goal of this program is to provide a vehicle to operate at depths to 20,000 feet (6,100 meters), thereby providing access to more than 98 percent of the ocean floor.

RUWS is designed in modules so that components can be interchanged for specialized experiments. The work vehicle carries two manipulators, one a heavy grabber and the other a highly articulated manipulator; television cameras, including a head-coupled system that gives the remote operator a sense of being present at the work site; and other instrumentation required for the successful completion of its tests (Figure 16).

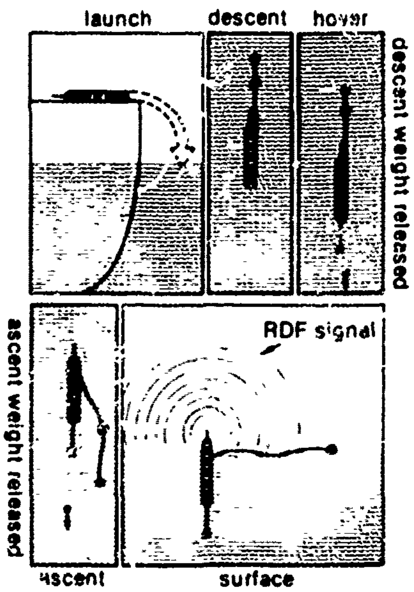

Figure 12. *Sonodiver's* operational sequence.

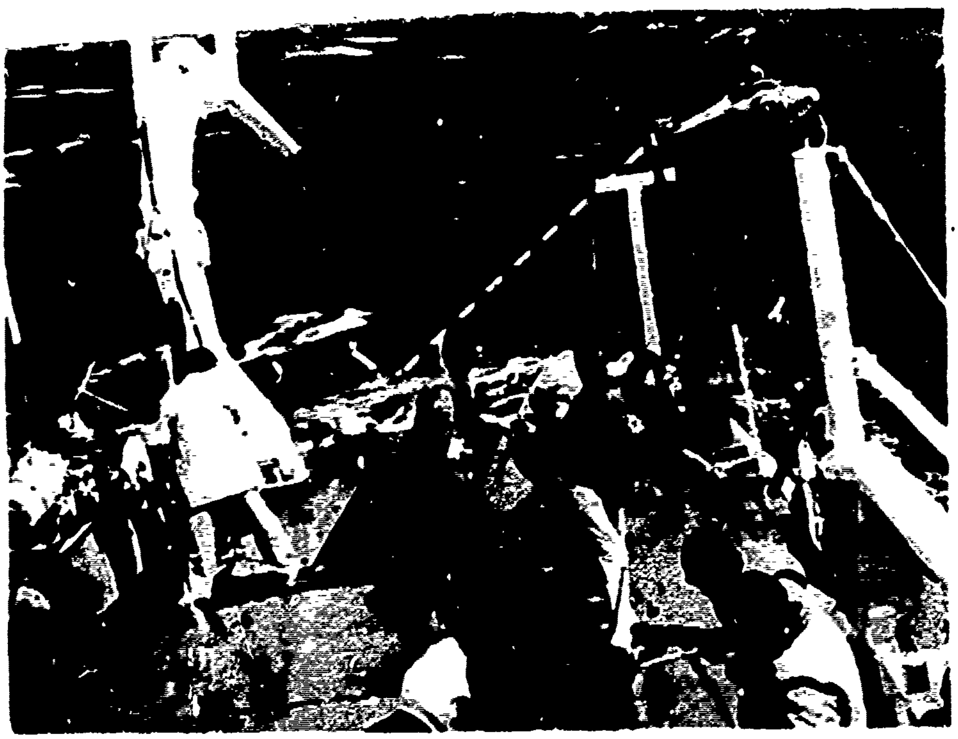

Figure 13. (a) *Sparbuoy*, often used with *Sonodiver*, makes long-term measurements of ambient noise near the sea surface.

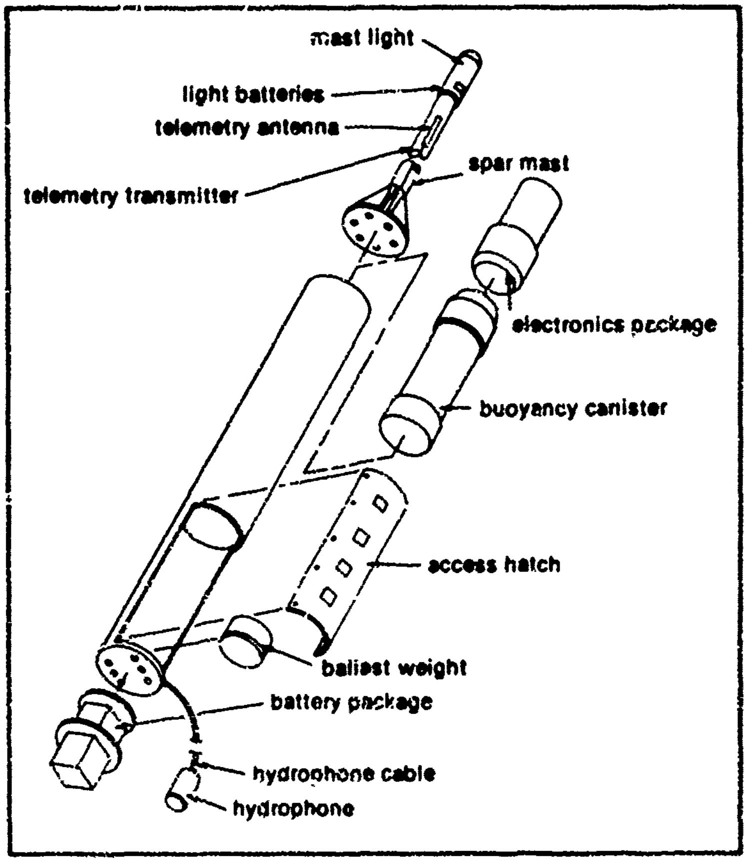

Figure 13. (b) *Sparbuoy's* main unit is the same size as *Sonodiver*, but it carries a mast 20 feet (6 meters) long.

Small, lightweight submersibles are typified by the *Snoopy* vehicles. *Electric Snoopy* is intended primarily to provide a remotely controlled underwater observation vehicles (Figure 17). Although it is only 42 inches (1.07 meters) long and 30 inches (0.76 meter) wide and weighs approximately 200 pounds (90.7 kilograms) in air, it can operate to depths of 1,500 feet (460 meters). A similar vehicle, *NAVFAC Snoopy*, has been designed for use by the Naval Facilities Engineering Command during ocean construction work. This *Snoopy* carries a neutrally buoyant reel and strong, lightweight, Kevlar line for implanting and recovering items from the seafloor.

The basketball-sized *RCV-125* (for "Remotely Controlled Vehicle") was developed by Hydroproducts, Inc. The vehicle (Figure 18) weighs 180 pounds (82 kilograms) and carries a television and light as well as sets of thrusters that give it mobility in all directions.

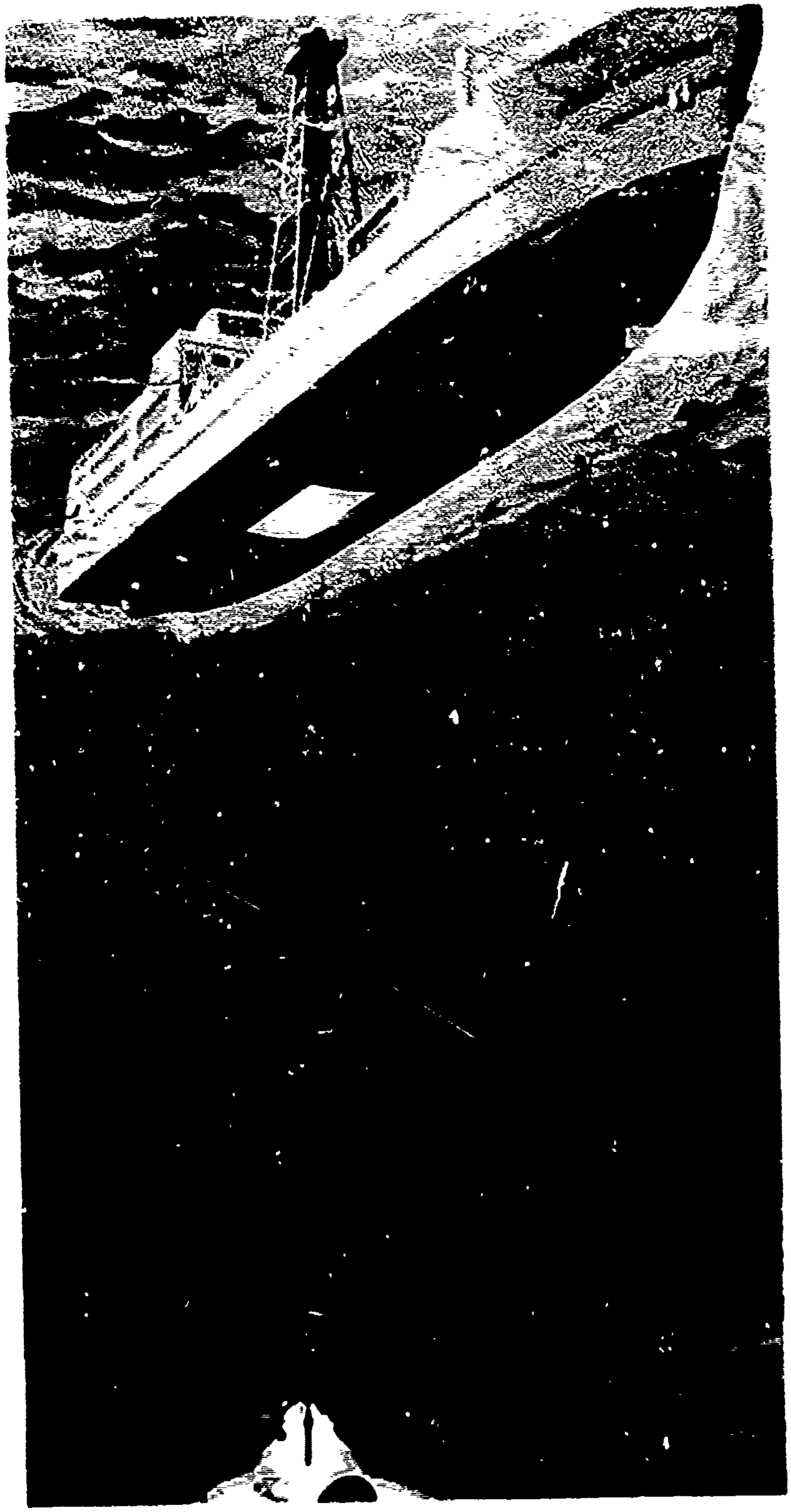

Figure 14. *Seaprobe* is a proven, remotely operated system.

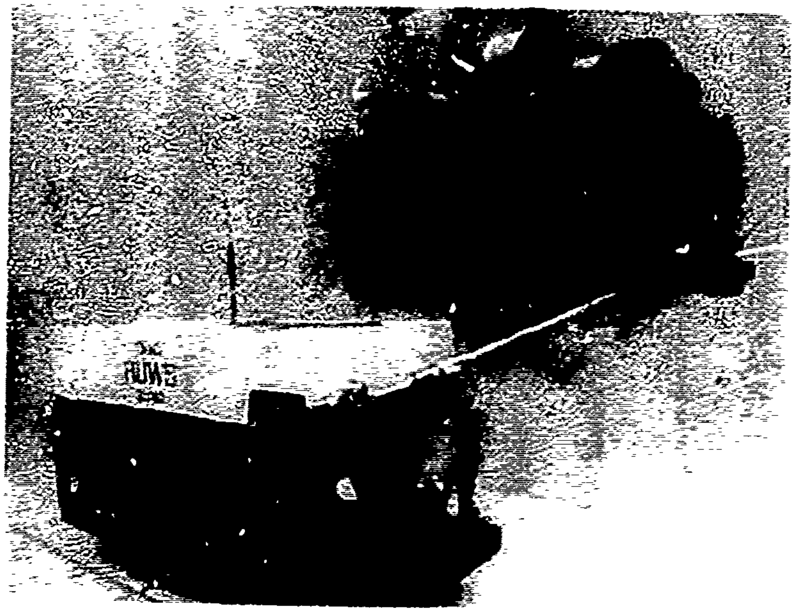

Figure 15. *RUWS* (for "Remote Unmanned Work System") consists of two major units, the primary cable termination, shown here at the right, and the work vehicle. The design goal is a depth capability of 20,000 feet (6,100 meters).

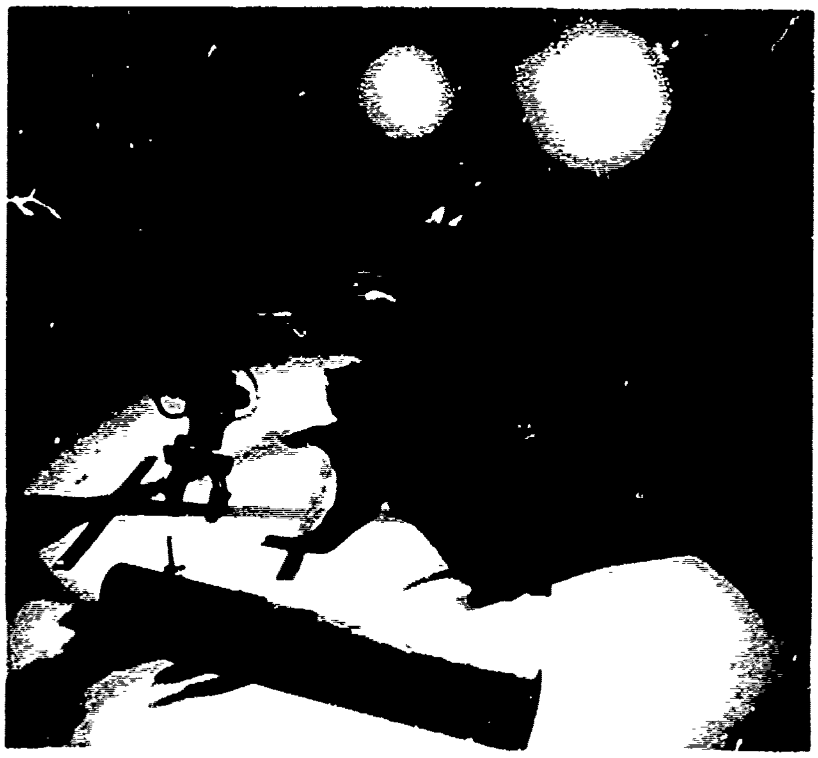

Figure 16. *RUWS* manipulator in operation during night pool tests.

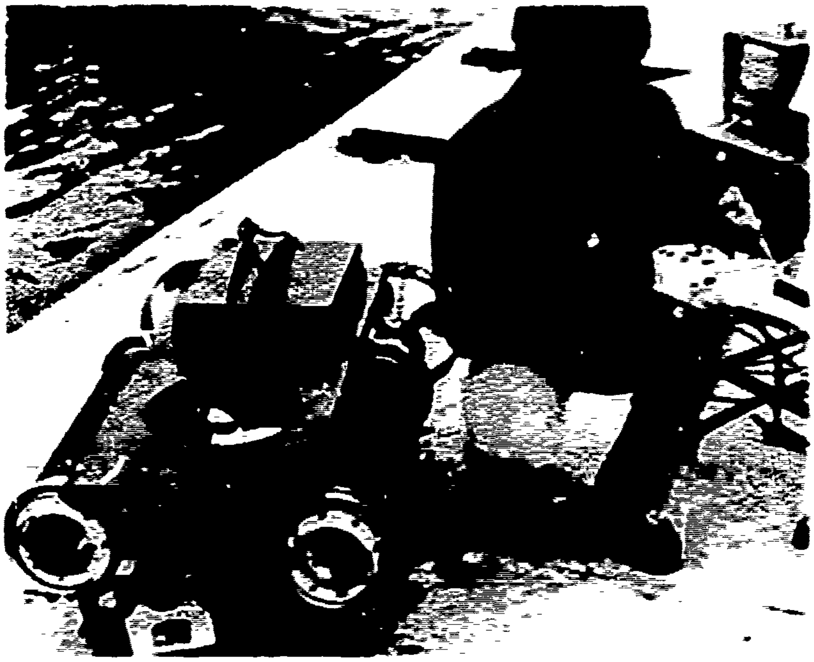

Figure 17. *Electric Snoopy* typifies the small, lightweight, remotely operated systems now available.

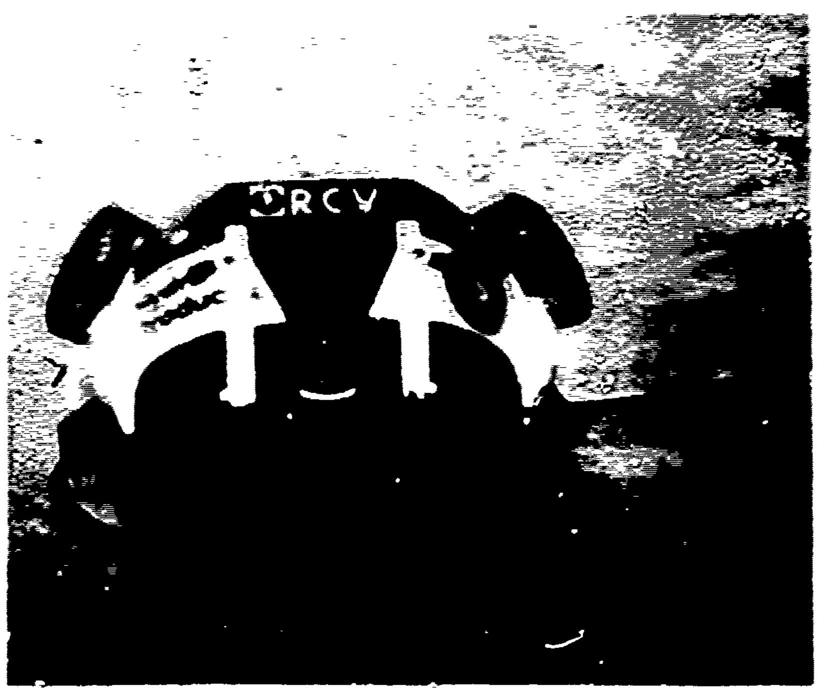

Figure 18. One of the smallest remotely operated systems is the Hydroproducts *RCV-125*. This vehicle weighs 180 pounds (82 kilograms).

CONCLUSIONS

Some conclusions can be drawn having come this far. First, it is recognized that, to meet the challenge of making a thorough and effective use of the marine environment and its resources, a full complement of manned and remotely manned systems will be required. Second, it is, however, imperative that remotely manned systems be used as much as possible. Remotely manned systems are better suited to most undersea work and exploration tasks for at least six reasons: relative economy of development in time and equipment costs when compared with manned systems, unlimited operational endurance on site by virtue of the cable link to the surface, surface control and coordination of project efforts (avoids clash of operational philosophies – he who is on the surface is in command), ability to perform in hazardous areas without endangering personnel, ability to change or modify all system components to meet individual tasks or range needs without affecting system safety or certification status, and ease of changing crews without disrupting the mission. Men simply leave their places at the control consoles and immediately their replacements are there to take over (Figure 19). In addition, because these systems are usually smaller and lighter, as well as remotely manned, the handling problem is significantly reduced.

Third, and this is complementary to the second conclusion, man should be included in a system only if he is absolutely necessary for the success of the mission, because his presence in a system drastically increases its cost. This cost is reflected not only in dollars, but also in more safety considerations, system complexity, handling problems, and time.

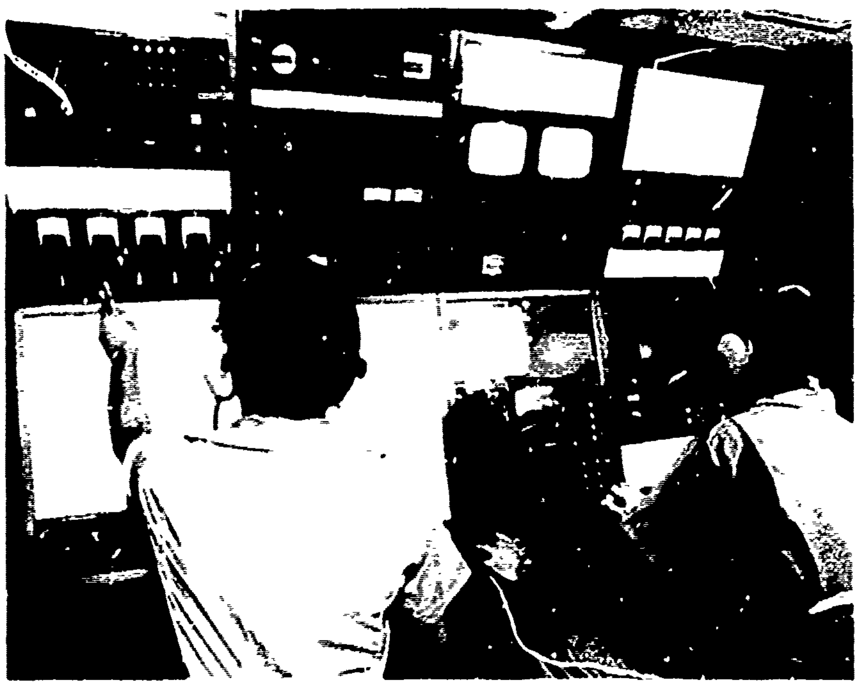

Figure 19. The *RUWS* control console aboard its support ship is representative of those used with large, remotely operated systems.

Also, if man's presence is necessary for a successful mission, it is most likely because the mission requires real-time, high-resolution sight. A corollary to this observation is that, it a man is needed for seeing, then provide him with a system which offers maximum visibility.

While the Navy's *Turtle* and *Sea Cliff* (Figure 20) are versatile research submersibles capable of performing search, recovery, photographic, and scientific tasks to depths of 6,500 feet (1,980 meters), they have only relatively small viewports through which the observer can exercise his ability to see. Something different from this type of submersible configuration is often required. At the present time there is a group of submersibles (Figure 21), which, besides being fully instrumented, provide maximum or panoramic visibility. Among this group are the totally transparent-hulled *NEMO, Sea-Link* and *Makakai. NEMO*, the first fully operating and certified submersible using an acrylic hull, is a self-contained system with a one-atmosphere environment. It carries its crew of two on missions to depths of 600 feet (180 meters), and its acrylic sphere affords the crew the all-round visibility that makes *Nemo* a superb observation platform. The *Sea-Link* makes use of an acrylic sphere like *Nemo's* which allows for the required visibility, but it also has a welded aluminum hull for diver transport and lock-out capability. Designed to operate at more than 3,000-foot (900-meter) depths, the *Sea-Link* will also enable a team of three divers to work at 1,600-foot (500-meter) depths. *Makakai*, "eye of the sea," lives up to its name. Also making use of a transparent acrylic sphere as its pressure hull, which permits all-round visibility, the *Makakai* is a two-man free-swimming submersible with an operating depth of 600 feet (180 meters). Its two pi-pitch cycloidal thrusters give the submersible a cruising speed of 0.5 to 0.75 knots

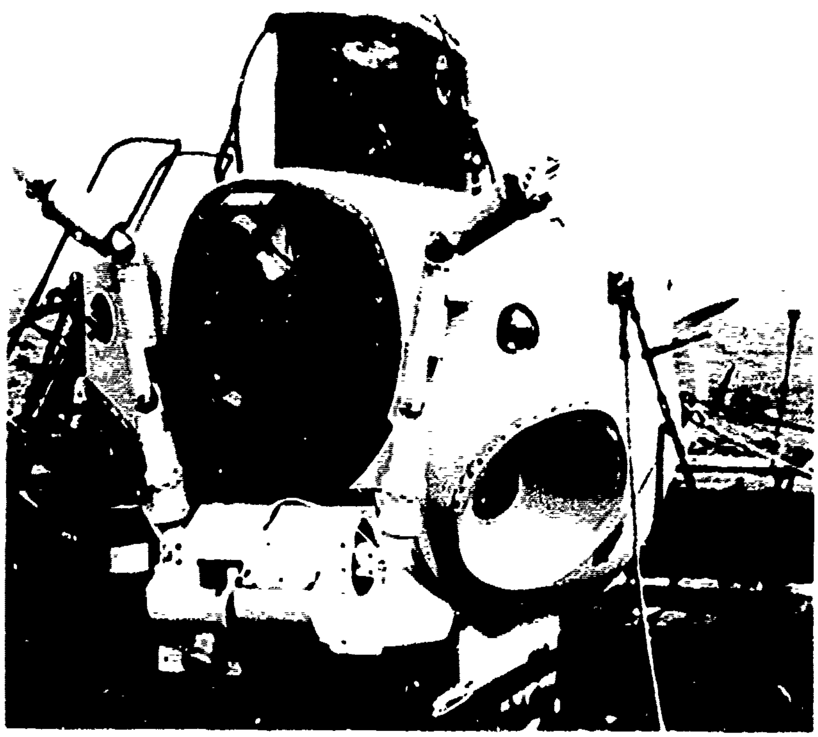

Figure 20. Manned research submersible *Sea Cliff* is a versatile vehicle.

NEMO

Sea Link

Makakai

PC-8

Deepview

Figure 21. Manned submersibles offering panoramic visibility

(0.3 to 0.4 meter/second) with a maximum speed of 3 knots (1.5 meters/second). At cruising speed *Makakai* can operate for 6 hours.

Additionally, several manned submersibles have been constructed with very large ports of transparent materials such as acrylic or glass. The Perry submersibles *PC-8, 14,* and *15*, several of the later Hyco (International Hydrodynamics Co.) submersibles, and the U.S. Navy's *Deepview* all fall into this category. The Perry *PC-8* is typical of the commercial boats. Equipped with navigation and control instrumentation, a communication system, and a manipulator arm, the *PC-8* can operate to depths of 230 meters for 2 hours of continuous running at a maximum speed of 2 meters/second or for 8 to 10 hours at 0.5 meter/second. *Deepview*, a two-man submersible with a transparent bow, is the first submersible to make use of massive glass as a significant portion of the pressure hull. Its nose is a large glass hemisphere 38 millimeters thick. *Deepview* currently operates to a depth of 33 meters at speeds from 0.50 to 1.5 meters/second for 6 hours. As viewports cast from glass ceramic or chemically surface strengthened glass become available submersibles like *Deepview* may dive deeper than the 610-meter limit of acrylic plastic hulls. Ceramic windows 200 millimeters in diameter have already been fabricated for use in unmanned systems (Figure 22).

When man is required in a system for his active seeing ability, these are the types of systems that make him most effective.

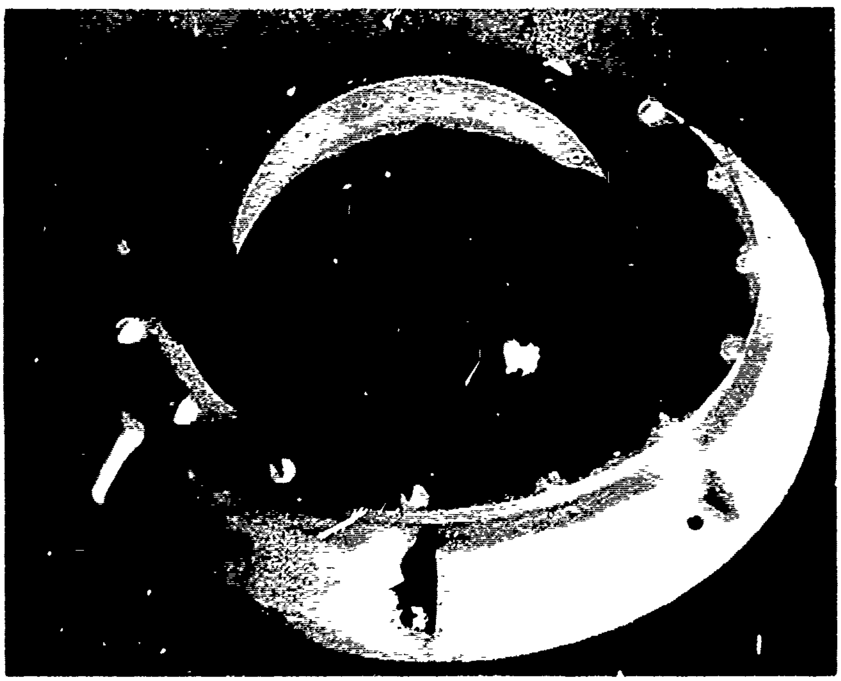

Figure 22. Glass ceramic windows will greatly increase the operational depth capability of submersibles like *Deepview*. The one shown is 8 inches (200 millimeters) in diameter and is intended for use in an unmanned system. Information gained in testing it will help in the design of larger windows for manned vehicles.

SUMMARY

In summary, this paper has acknowledged the overall goal of developing, promoting, and supporting a national operational capability for man to work under the sea in order to achieve a better understanding, assessment, and use of the marine environment and its resources. At the same time, it noted in Table 1 some of the particular data requirements that have to be met if the overall goal is going to be attained. It gave examples of tasks various systems will be confronted with as the marine environment is made more and more available to man. Then the question was asked, Why man? Why do we need man in a system? Or, more specifically, *where* in the system should the man be? Should he operate at the work site, or remotely, from a surface craft? Why does he want to be at the scene? Is he necessary? Is he superfluous? The answers to these questions reveal that all exploration, research, and work represent a compromise between desire and economics. Man's desires in undersea exploitation exceed his ability to pay for them. To put man under the sea entails high costs in money, time, and complexity. Thus, the following conclusions were made. Both manned and unmanned systems are necessary to attain the goal. However, it is obligatory that unmanned systems be considered first and used whenever and wherever possible. Man should be considered for systems only if it is essential to the mission's success. And, since what makes man essential in a system is his ability to provide active, real-time, high-resolution sight, then that system should enable him to exercise this ability to the greatest degree. As Aristotle wrote in his *Metaphysics*, Book I:

> All men by nature desire to know. An indication of this is the delight we take in our senses; for even apart from their usefulness they are loved for themselves; and above all others the sense of sight. For not only with a view to action, but even when we are not going to do anything, we prefer seeing (one might say) to everything else. The reason is that this [seeing], most of all the senses, makes us know and brings to light many differences between things.

Therefore, if man must be in the system, give him visibility, panoramic visibility. But, however useful, exciting, and necessary manned systems may be, the majority of undersea tasks facing man can be performed more safely and economically, and as thoroughly, with remotely operated, unmanned systems.

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